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(54) **Composite insulation**

(57) A composite insulation of glass fibres and epoxy having a more nearly uniform coefficient of thermal expansion in all three planes for use in superconductor applications.

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## Description

This invention relates to composite insulation such as that used with superconductors.

Glass reinforced epoxy insulation structures are often used in superconducting magnets. Large magnets using Cable-in-Conduit-Conductors (CICC) require insulation and structural support for the CICC turns.

The CICC conduit is chosen to match the CTE (Coefficient of Thermal Expansion) of the superconducting material. The superconducting material is a brittle intermetallic that is formed by reaction at high temperatures. The CICC provides support to the brittle superconducting material and an enclosure for cooling fluid which is necessary for superconducting performance. Too much strain imparted to the superconducting material will also degrade performance. The CICC conduit is chosen to match the thermal expansion of the superconducting material from the reaction temperature to room temperature for coil fabrication and to cryogenic (e.g. 5K) temperature for superconductor operation.

To provide structural support and insulation the CICC conduit is surrounded by the insulating material. Stresses are induced into the structure (CICC coil with turns surrounded by insulating material, glass roving and epoxy) by reaction of Lorentz forces when the coil is energized and upon cooldown of the structure due to the difference in thermal expansion between the insulating material and the CICC conduit, the geometry of the coil, and the anisotropic nature of the thermal coefficient of expansion and of the anisotropic nature of the strength and modulus of elasticity, due primarily to the two-dimensional (2D) nature of the composite material of the insulation. By 2D nature, it is meant that in the direction perpendicular to the warp-fill plane, the composite exhibits epoxy-like properties. These resulting stresses in the insulation are very large and will likely cause cracking in operation.

For some projects, the existing insulation design (using the 2D composite support and insulation system given above) results in unacceptably large stresses which violate the design guidelines and requirements. This provides risk of structural and electrical degradation or failure. Given the expense of the magnets and the associated projects, risk reduction and improved reliability achieved with this design appear prudent.

According to one aspect of the invention there is provided a three-dimensional composite insulation comprising a three-dimensional weave of glass fibres and an epoxy combined with the weave.

According to another aspect of the invention there is provided a method of using a three-dimensional composite insulation with a cable-in-conduit-conductor material and a superconducting material, the method comprising:

selecting a three-dimensional weave of glass fibres and epoxy having a substantially uniform coefficient of thermal expansion in three orthogonal planes

that is substantially the same as the coefficient of thermal expansion of at least one of the conduit material or the superconducting material; and insulating the conduit material with the three-dimensional weave of glass fibres and epoxy.

A preferred embodiment of this invention avoids the problems associated with two-dimensional insulating materials, such as unacceptable stresses in the plane perpendicular to the warp-fill plane caused by anisotropic coefficient of thermal expansion of the material.

The preferred embodiment provides a structural support and insulating material for superconductors that has a more nearly uniform coefficient of thermal expansion in all three planes; the insulating material results in decreased stresses on the material and on other parts of a superconductor device upon cooldown to cryogenic temperatures. The preferred insulating material will not adversely affect the operation of the superconductor.

For a better understanding of the invention, its operating advantages and specific objects attained by its uses, reference is made to the accompanying descriptive matter in which a preferred embodiment of the invention is illustrated.

The preferred embodiment of the invention introduces a tailored isotropic insulation whose thermal expansion characteristics more closely resemble those of the CICC conduit with which it is to be used and whose mechanical properties are nearly isotropic. By providing an insulating material of nearly the same coefficient of thermal expansion as the CICC conduit and one that has nearly uniform coefficient of thermal expansion in all three directions, the stress in the insulation and the structure upon cooldown to cryogenic temperature from room temperature will be within acceptable limits. Also, the stresses are strongly affected by the isotropic nature of the glass fibres in the insulation matrix of the composite and their strength and modulus of elasticity. To obtain these isotropic coefficients of thermal expansion and mechanical properties, a three-dimensional (3D) weave of glass fibres is used so that the strength, modulus and expansion are more nearly the same in all directions.

In a 3D weave, warp fibres tie together more than one warp-fill plane. The glass and epoxy of the composition are chosen to provide the best match of coefficient of thermal expansion with that of the CICC conduit.

One choice of CICC conduit material that may be used is Incoloy 908. This is used to match  $Nb_3Sn$  superconducting material. This combination is common in high performance or high field superconducting magnets.

The insulating material is also chosen so that the coefficients of thermal expansion most closely match those of the CICC conduit and the superconducting material, achieved by tailored 3-D properties. In this example, the insulating material to be used with the Incoloy 908 and  $Nb_3Sn$  is S2 glass fibre with epoxy fill

composed of CTD 101K. Alternatively, in another embodiment, there is used an initial KAPTON (registered trademark) or polyimide layer wrap with S2 glass fibre and epoxy fill. Also possible is a cruciform or T-shaped 3D woven corner roving designed to distribute the stress load around and through corners of the CICC while avoiding epoxy-rich regions.

While a specific embodiment of the invention has been described in detail to illustrate the application of the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

#### Claims

1. A three-dimensional composite insulation comprising a three-dimensional weave of glass fibres and an epoxy combined with the weave.
2. A three-dimensional composite insulation according to claim 1, wherein the glass fibres are of the S2 type and the insulation is in combination with a superconducting material which matches the insulation in three-dimensional coefficient of expansion.
3. A method of using a three-dimensional composite insulation with a cable-in-conduit-conductor material and a superconducting material, the method comprising:

selecting a three-dimensional weave of glass fibres and epoxy having a substantially uniform coefficient of thermal expansion in three orthogonal planes that is substantially the same as the coefficient of thermal expansion of at least one of the conduit material or the superconducting material; and insulating the conduit material with the three-dimensional weave of glass fibres and epoxy.

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